IACS Summary of the IMO GBS and the Harmonised Common Structural Rules

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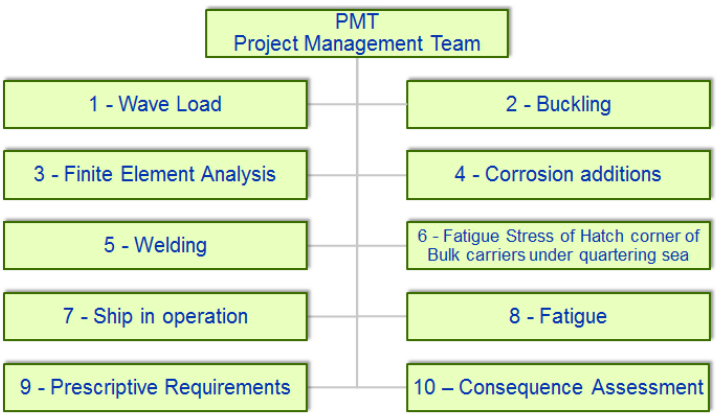
Abstract

This paper briefly describes the IMO Goal Based Standards and how they are being addressed within the IACS harmonised Common Structural Rules (CSR-H). The paper describes how the harmonised CSR address the GBS functional requirements within the rules themselves or as documented in the CSR Technical Background documents. Issues relevant to shipbuilders such as documentation related to inventory of materials for future ship recycling and the Ship Construction File are also highlighted. An update of the consequence assessment, which compares the requirement of the draft harmonised CSR with the offered design, is also presented. Finally, a status update regarding the submission of documents to be forwarded to the IMO for the GBS verification audits is given.

1 Introduction

IACS Common Structural Rules (CSR) for oil tankers and bulk carriers were developed as two separate rule sets in 2002-2005 and came into force in April 2006. Already in 2006 IACS had promised to harmonize these rules, in order to have common rule principles, methodology and criteria for both vessel types. After some initial planning at the end of 2007 the work started in 2008. Ten project teams made up of about 70 specialists from IACS societies have been engaged in this development, see Figure 1.

Figure 1 Project teams in the harmonization project



2 Description of GBS

In parallel with the development of CSR by IACS, the International Maritime Organization (IMO) introduced the "goal-based ship construction standards (GBS)" in November 2002 and its Maritime Safety Committee (MSC) commenced detailed technical work on developing the GBS at its 78th session in May 2004.

In May 2010, the MSC, at its 87th session, finally adopted Resolution MSC.290(87) – Adoption of the Amendments to the SOLAS (Chapter II-1/Regulation 3-10) and Resolution MSC.287(87) – Adoption of the International Goal-Based Ship Construction Standards for Bulk Carriers and Oil Tankers.

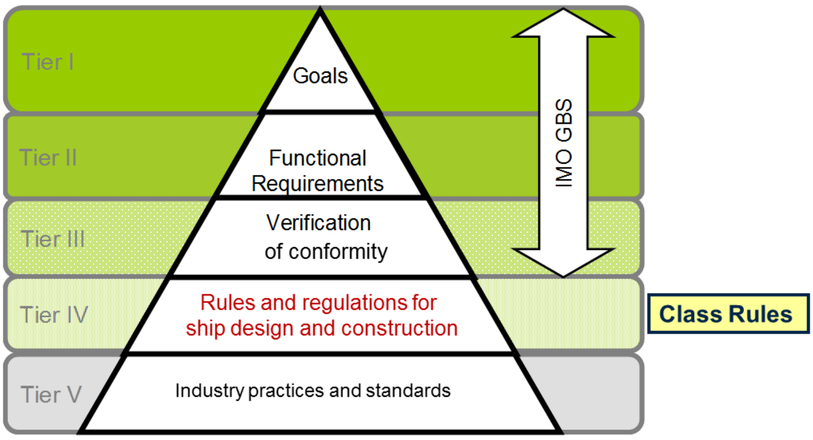
In addition, the following two guidelines were adopted or approved as Resolution MSC.296(87) and MSC.1/Circ.1343 respectively.

- *Guidelines for Verification of Conformity with Goal-Based Ship Construction Standards for Bulk Carriers and Oil Tankers*
- *Guidelines for the Information to be included in a Ship Construction File* (SCF)

The Standard was organized using a five-tier system as shown in Figure 2 with the IMO GBS consisting of the upper three tiers. The class rules correspond to Tier IV and they shall be verified as conforming to the Tier I goals and Tier II functional requirements, based on Tier III, "*The Guidelines for Verification of Conformity with Goal-Based Ship Construction Standards for Bulk Carriers and Oil Tankers*".

It should be noted that the GBS contain goals and functional requirements that the developers of Rules and/or Regulations use to verify their Rules and/or Regulations. In other words, the GBS is a set of "rules for rules" and are not directly applied to individual ship designs.

Figure 2 IMO GBS - Five-tier system



Within the GBS Tier II there are 15 main functional requirements as listed below.

II.1 Design life
II.2 Environmental conditions
II.3 Structural strength
  II.3.1 General design
  II.3.2 Deformation and failure modes
  II.3.3 Ultimate strength
  II.3.4 Safety margins

- II.4 Fatigue life
- II.5 Residual strength
- II.6 Protection against corrosion
  - II.6.1 Coating life
  - II.6.2 Corrosion addition
- II.7 Structural redundancy
- II.8 Watertight and weathertight integrity
- II.9 Human element considerations
- II.10 Design transparency
- II.11 Construction quality procedures
- II.12 Survey during construction
- II.13 Survey and maintenance
- II.14 Structural accessibility
- II.15 Recycling

3 Application of GBS in CSR-H

To understand how the Goal Based Standards have been applied in the IACS harmonised Common Structural Rules it is useful to review what is already covered in the current CSR-OT, what gaps were identified between the GBS and the new CSR-H development, and which completely new topics would need to be addressed from scratch in the CSR-H.

3.1 What is already covered by current CSR-OT

When the IACS Pilot projects started in 2003, the GBS guidelines were still under discussion and only early drafts were available. But in order to accommodate available GBS concepts, IACS decided to consider in their rule development some GBS parameters estimated as sufficiently developed.

The first main assumption was to consider the wave scatter diagram of the North Atlantic. This assumption was commonly agreed in the discussion on the GBS topics.

The second main item also agreed was to consider the design ship life equal to 25 years. This design life has consequences on several ship parameters. The first one is the long term period to consider for the wave loads. Another is the corrosion model to consider for this design life, and finally, the influence on the fatigue damage calculations.

These two main assumptions regarding wave environment and design life were so considered in the early development of the Common Structural Rules.

3.2 Gap analysis

After the first draft issue of the CSR-H, the different project teams involved were requested to make the first self-assessment of the text against the GBS guidelines. To assist them for the assessment of the CSR-H against the GBS, IACS implemented an Expert Group gathering experts from each Class Society and a specialised project team (PT/GBS) especially dedicated to appraise any gaps between the GBS guidelines and the proposed CSR-H text. The main objective after the gap analysis was to identify and help to provide solutions to the project teams in charge of the Rule development.

Based on this analysis some updates in the Rule text and technical backgrounds were made to satisfy the GBS requirements. The GBS gap analysis resulted in additional IACS work needed to bring the CSR-H into compliance with the GBS, and also laid the foundation for documenting and justifying that the CSR-H and other supporting documents comply with the GBS. This was documented by providing references in the Rules and in the technical backgrounds indicating where and how the topic is addressed. An example of such a summary sheet is given in the Appendix.

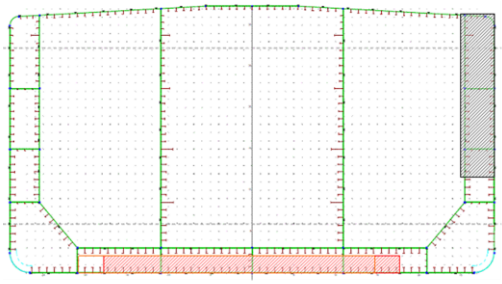
3.3 New items not covered in current CSR-OT

From the beginning of the CSR-H development, some of the new GBS requirements were identified as not being fully covered by CSR-OT and therefore would have to be addressed in the CSR-H. These they were: residual strength, structural redundancy and the wave induced hull girder vibration due to whipping and springing.

3.3.1 Residual strength (collision and grounding damage)

The GBS guidelines request that the rules provide a reasonable level of residual strength after damage (e.g., collision, grounding and flooding). The evaluation of the residual strength of the hull girder after a collision or a grounding damage was introduced based on existing requirements developed by some IACS members. This evaluation is made for ships greater than 150 m in length. An assumed damage extent in height and depth is defined for each damage type. In line with the Rule principles, the ultimate strength of the hull girder is checked within the cargo area and in the machinery space for both collision and grounding scenarios. This is done by separately considering that the assumed damage zone is removed from the hull properties. A typical example of the collision (side damage) and grounding (bottom damage) extent is provided in Figure 3.

Figure 3 Example of collision and grounding damage extent



Generally the flooded condition of an oil tanker does not govern the local structural scantlings as far as the cargo tank is concerned. However, this loading condition was introduced in the harmonised CSR to evaluate that the ship can survive the assumed damage extent when dry or void space compartments are flooded by the sea water. Relevant solutions derived from the bulk carrier approach were used in this respect.

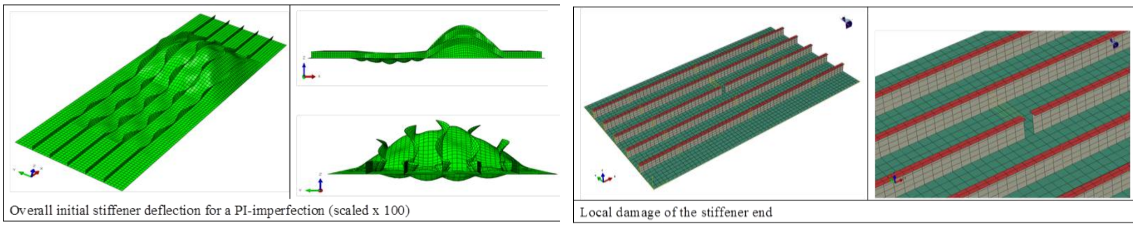
3.3.2 Structural redundancy

Structural redundancy is not a new concept in IACS as this approach was already applied for the side frames of single side skin bulk carriers. This approach was implemented to avoid the single failure of a side frame leading to an overloading of its side frame neighbours which could cause collapse and lead to the progressive collapse of adjacent frames. In other words it was introduced to avoid the domino effect of side frame failures. The result of the IACS approach was the scantling reinforcement of the side frames for yielding and for buckling. Subsequently IMO requested the same approach be extended to the areas of the cargo hold structure subject to impact by grabs.

IMO has now extended the same concept to the remaining structure of bulk carriers and to the structure of oil tankers. With this expansion of application, the type of structure to which it is applied is different. An example, such as a stiffened panel surrounded by primary supporting members which is subject to localised damage, i.e. local permanent deformation, cracking or weld failure, is shown in Figure 4.

Based on in-service experience of IACS members, a stiffened panel typically does not collapse under a localised damage such as that which is defined. It is no longer a question of grab impact on the structure generating deformation or cracks. The considered damages are relative to the normal operating ion sea-going conditions. Therefore in the IACS GBS submission IACS elected to demonstrate that the stiffened panels of different sizes made of elements with different scantling but of standard and usual design in the shipping industry, have inherent structural redundancy to withstand those localised damages. This work has been submitted to eminent professors of Japanese and European universities in Japan and Europe who have agreed on the methodology. At the time of writing this paper, the task is still in progress but close to being concluded in time for the IMO GBS submission.

Figure 4 Examples of localised damages on a stiffened panel



Overall initial stiffener deflection for a PI-imperfection (scaled x 100)

Local damage of the stiffener end

3.3.3 Fatigue due to whipping and springing

The GBS guidelines stipulates that the rules take into consideration the slamming (e.g., whipping) and vibration-induced fatigue effects (e.g., springing or propeller induced vibrations) in the fatigue assessment and to provide justification if these are not explicitly considered.

After the analysis of the reported damages including all types of phenomena, including springing and whipping, it is noted that on pre-CSR ships the fatigue damage due to springing and whipping on deck longitudinals is generally not found to be a critical issue.

The following is a summary of the major opinions concerning the fatigue life identified through the discussion at IMO MSC in the process of establishing GBS (e.g. para. 22 of MSC 80/WP.8, 18 May 2005)

- Most ships do not trade exclusively in the North Atlantic.
- Using the North Atlantic environmental conditions provides a suitable safety margin against the uncertainties in calculating fatigue life.

IACS reviewed the statistics on the operating routes of existing bulk carriers and oil tankers. The effect of whipping and springing from the statistics has been analysed in a technical background report showing that that failure probability for the ships which may be affected by the effect of whipping and springing is estimated between 2.3% and 7.2% among the population of ships that actually trade full time in the North Atlantic. Therefore, it can be estimated that around 0.34% of oil tankers face the risk of fatigue damage due to springing and whipping. It can be concluded for this topic that the fatigue life specified in the CSR-H has a sufficient safety margin against the effects of whipping and springing. Over the years the fatigue criteria included in the Rules have been calibrated against the actual overall service experience of ships, including actual springing and whipping fatigue damage. Therefore, the wave induced hull girder vibration has been implicitly included in the IACS members' Rules as well as in CSR-H fatigue procedure.

4 Overview of CSR-H

4.1 Wave loads

In developing the design wave loads for strength assessment, the following conditions have been considered as the basis for the harmonised CSR:

- North Atlantic wave environment, scatter diagram is given in IACS Rec 34(1).
- Pierson-Moskowitz wave spectrum.
- Angular spreading of the wave energy given by the function cos ?
- Equal heading probability.

- 30 degrees step of ship/wave heading.
- Design life of 25 years (corresponding to the probability level $Q = 10^{-8}$).
- Ship speed equal to 5 knots for yielding and buckling assessment.
- Ship speed of ¾ of design speed for fatigue assessment.

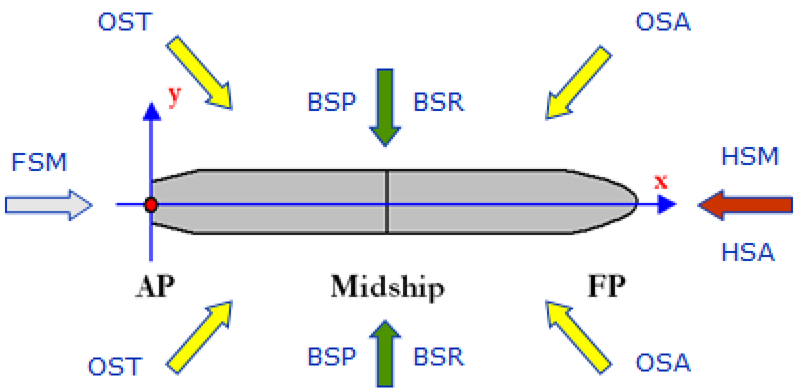
The design load concept in CSR-OT has been replaced by an improved version of the Equivalent Design Waves (EDW) concept used in CSR-BC.

4.1.1 The Equivalent Design Waves (EDW) concept

IACS developed a practical estimation method of using Equivalent Design Waves (EDWs) which are the regular waves that can generate response values of stresses equivalent to the long-term prediction values of stresses. In the harmonised CSR, the EDW method is used to set the design loads which include lateral loads (external and internal pressures) and hull girder loads in waves, see Figure 5. HSM and HSA are head sea cases with maximising hull girder bending moment and acceleration respectively. OST and OSA are the oblique sea cases maximising hull girder torsional moment and acceleration respectively. BSP and BSR are the beam sea cases maximising sea pressure and roll motion respectively and finally FSM which is the following sea case maximising the hull girder bending moment. The development of the EDWs has been based on the following four steps:

- The dominant load components which are most critical for the strength of ship structures were identified based on the detailed structural analyses of global FE models subjected to direct wave loads.
- The equivalent design waves were defined together with the regular design wave conditions such as wave encountering angles, wave lengths and wave heights.
- The hydrodynamic pressure distributions under each EDW were developed.
- The load combination factors for hull girder loads, ship motions and acceleration due to ship motions under each EDW were developed.

Figure 5 Equivalent Design Waves (EDWs)



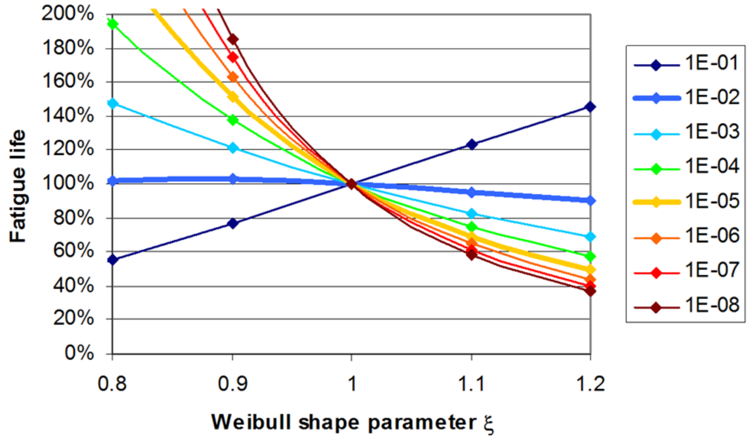
The load combination concept in CSR-OT with '*Static*' for frequent loads/functional loads and '*Static + Dynamic*' for stillwater loads combined with wave loads in seagoing conditions have been maintained.

4.1.2 Fatigue loads at a probability level 10^{-2}

In CSR-OT, the dynamic loads for fatigue assessment are envelope loads, which are used to calculate envelope stresses for each load component, vertical and horizontal hull girder bending moment, sea pressure and internal loads. The combination of these load effects are done in the final stress combination. The harmonised CSR has instead adopted an EDW concept for dynamic load cases applied in the fatigue assessment, which is a more generic concept than the current method in CSR-OT which was specially developed for oil tankers. The results from direct calculations of loads used for the development of the EDW method for fatigue assessment have been obtained based on the same considerations as listed in Section 4.1 above.

All dynamic load cases as shown in Figure 5 except for OSA and HSA are applied for the fatigue assessment. In order to avoid the need to adjust the Weibull shape parameter when doing fatigue calculations, it was decided to define the reference dynamic loads for fatigue at a probability level of 10^{-2}. As shown in Figure 6, dynamic loads at 10^{-2} level will result in the same fatigue life for a wide range of Weibull shape parameters.

Figure 6 Sensitivity of Weibull shape parameter on fatigue life for dynamic loads at probability level from 10^{-1} to 10^{-8}



4.2 Corrosion

The corrosion approach and the corrosion protection of the ships have not been significantly changed from CSR-OT or CSR-BC, but additional studies were performed to confirm the corrosion addition values and the issue of protection against corrosion in CSR-H.

4.2.1 Reanalysis of corrosion data, increased database

One of the main changes in the scantling philosophy between the CSR and pre-CSR is the direct link between the wastage allowance given during the ship's life-cycle and the corrosion additions used for new building assessment. The value for wastage allowance considered in the CSR is the sum of the corrosion addition and the reserve thickness anticipated during survey intervals. This allowance represents the maximum diminution of all structural members permitted in service. This wastage allowance is approximately equal to the diminution value at 95 % cumulative probability for 25 years, which corresponds to the mean value plus two standard deviations. The corrosion values were re-analysed due to additional data provided by the International Chamber of Shipping (ICS), and IACS itself.

The initial database collected approximately 600,000 thickness measurement data samples from single hull tankers and single side skin bulk carriers of age 5 to 27 years. The additional data obtained from IACS members were for ships mostly 15 years of age or older. Only four vessels from ICS had sufficient information to be able to consider them in this analysis. The ICS vessels were all bulk carriers and were of age 21 years to 27 years.

Table 1: Additional Corrosion data from IACS & ICS

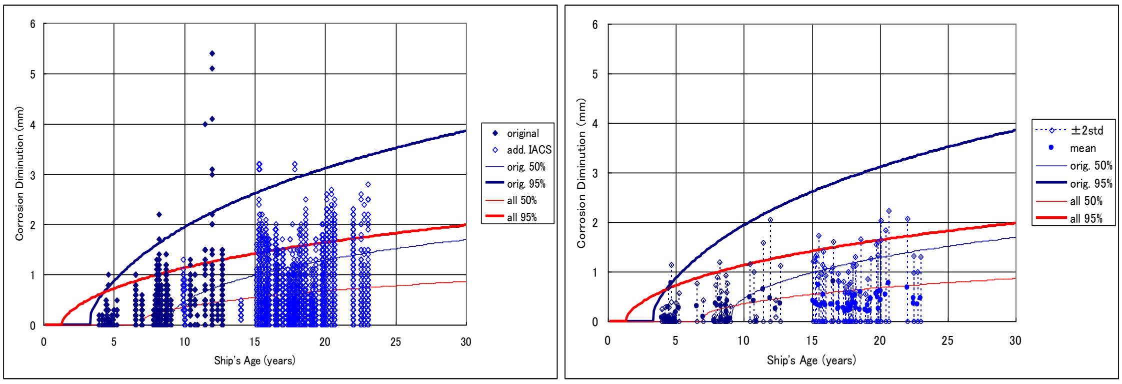
Ship Type	No of data points	No. of reports	No. of ships
Tanker*	373,818	57	57
Bulk carrier	1,369,004	175	146

* All tankers considered are 1978 MARPOL (as amended) compliant.

The new corrosion data, along with the original data, was analysed using the probabilistic corrosion model as defined for CSR-OT. Comparisons with probability plots for the original data were made to evaluate the impact of the new data on estimated corrosion diminution.

An example of the results of the re-analysis for the deck structure is shown in Figure 7. The plot on the left of the figure shows the actual observed diminution for the vessels in the database and the lines for cumulative probability at 50% and 95%. The plot on the right shows the mean values and mean + 2 standard deviations.

Figure 7 Weather deck plating of a cargo tank (t_c = 4.0mm)



The conclusion of this reanalysis shows that the corrosion additions in the existing CSR as well as those in the harmonised CSR are adequate for the purpose.

4.2.2 PSPC is removed as a classification item

The CSR-OT entered into force on 1 April 2006, however the IMO PSPC ("Performance standard for protective coatings for dedicated seawater ballast tanks in all types of ships and double-side skin spaces of bulk carriers", Resolution MSC. 215(82)) was not adopted by IMO at that time. IMO later adopted the PSPC on 8 December 2006, but the entry into force would come later. Therefore IACS decided to make mandatory the PSPC requirements as per the Classification Society rules upon the IMO adoption date.

On 11 July 2012 the IMO PSPC entered into force as a statutory item and therefore the situation has now changed. In the CSR-H, it was decided to come back to the normal regime, i.e. to separate the class and the statutory items. Therefore IACS removed the IMO PSPC for the ballast tanks and void spaces from CSR and did not introduced any other IMO requirements regarding the protective coating for the cargo tanks in CSR-H.

4.3 Hull girder ultimate strength

Some modifications were introduced in the hull girder ultimate strength of the CSR-H. The first one was to avoid having two methods for the appraisal of the ultimate bending moment and the second was to introduce a coefficient to take into account the local bending of the double bottom.

4.3.1 Incremental method

As a general policy, as far as possible IACS has tried to eliminate alternative areas of the Rules where two possible solutions are offered. This was the case for the determination of the hull girder ultimate bending capacity calculated by the single step method or by the incremental-iterative method. As the single step method was used only for oil tankers, it was decided in the harmonisation process to remove the single step method and to keep only the incremental method.

4.3.2 Double bottom influence

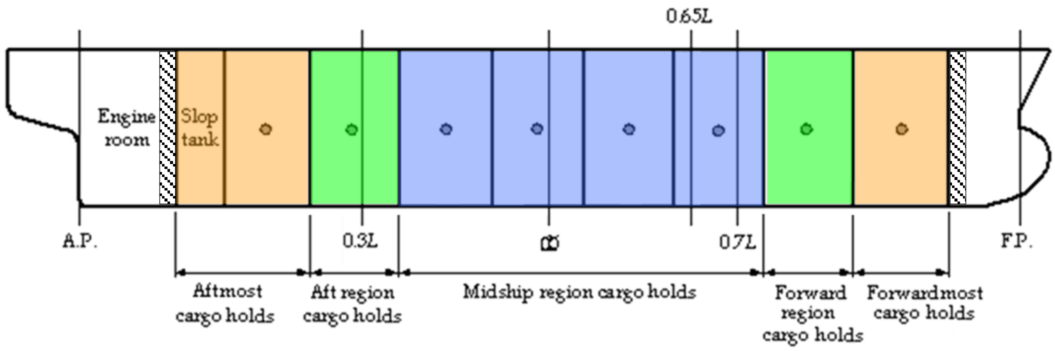
Where there is a large difference between external pressure acting on the bottom plating and internal cargo pressure loading the inner bottom plating, e.g. alternate loading condition, the double bottom is subject to a significant deformation and biaxial compressive stresses appear in the bottom plating in way of the mid-tank area and shear stresses load the end of longitudinal girders in addition to hull girder stresses. These additional biaxial and shear stresses reduce the overall hull girder ultimate capacity. To account for this effect, a double bottom factor, γ_{db}, was introduced to consider the decrease of hull girder ultimate capacity by the above mentioned stresses corresponding to double bottom deformations. This effect obviously appears when the tanker is in the hogging condition. Consequently, the γ_{db} coefficient was fixed at 1 in the sagging and at 1.1 in the hogging condition.

4.4 Direct Strength Analysis

4.4.1 Scope of FE calculations

After the release of the current CSR, industry expressed concerns about the scope of the FE application. The regions outside amidships were considered to be not sufficiently covered by the means of direct strength analysis. IACS agreed to improve its approach and increase the scope of the FE verifications. As shown in Figure 8, the scope in the CSR-H now covers the entire cargo hold region as well as the transition area forward and aft of the cargo region.

Figure 8 Scope of FE calculation



In line with this extension of the checked area, corresponding loading combinations outside amidships and for the foremost and aftmost cargo holds were developed. The boundary conditions, especially for the ends of the cargo area, were reconsidered and adjusted for this purpose.

4.4.2 Increased screening

The details to be checked by screening method in the midship area for CSR-OT are now to be checked in the full cargo area in CSR-H. In addition, some details have been added to the current list of details for the screening check, such as:

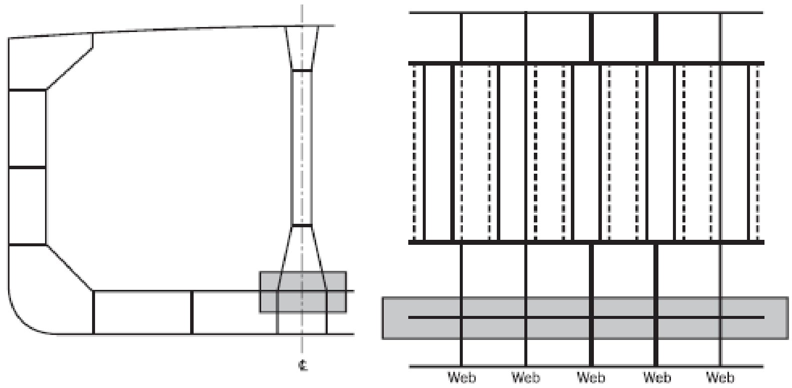
- Connections of transverse lower stool to double bottom girders and longitudinal lower stool to double bottom floors,
- Connection of lower hopper to transverse lower stool structure,
- Connection of topside tank to inner side,
- Connection of corrugation and upper supporting structure to upper stool.

Outside amidships, the screening procedure is applicable to

- Hopper knuckle,
- Connections of corrugation to adjoining structure.

Figure 9 illustrates some of the added items.

Figure 9 Example of additional details to be screened



4.4.3 Fine mesh FE scope increased

In addition to the hopper knuckle, additional details are to be checked by way of fine mesh regardless of the calculated stress level found in the global models. They are:

- Connections of deck and double bottom longitudinal stiffeners to transverse bulkhead,
- Connections of corrugated bulkhead to adjoining structure.

4.5 Buckling

The control of buckling consists of three modules:

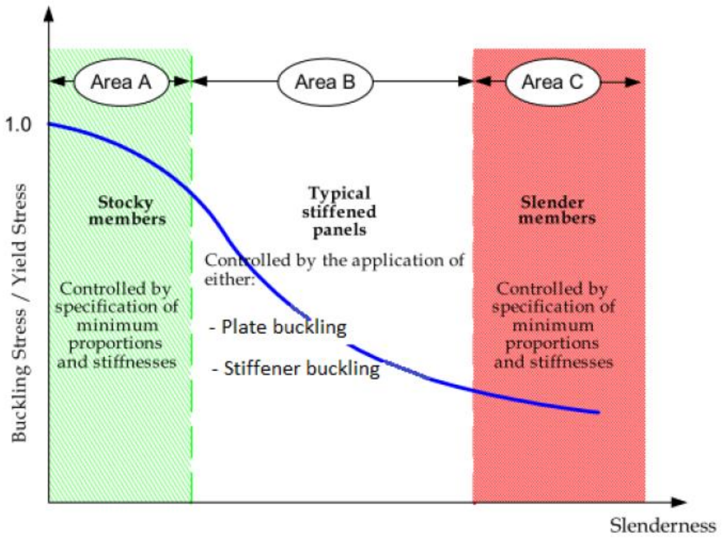
- Slenderness requirements of plates, longitudinal and transverse stiffeners, primary supporting members and end brackets,
- Prescriptive buckling requirements for members subjected to hull girder stresses as plates, longitudinal stiffeners and transverse stiffeners,
- Buckling requirements of the FE analysis for the plates, stiffened panels and other structures as cross ties.

The slenderness criteria are based on CSR-OT and consist of maximum permissible slenderness expressed as minimum thickness requirements, e.g. minimum thickness of plates, stiffener web or stiffener flange. For plates which will be assessed for buckling based on actual stress level, this requirement is a high slenderness requirement to avoid very thin plates resulting in very flexible structures with low stiffness. This is visualized as area B in Figure 10. For flanges of stiffeners and primary supporting members a low slenderness requirement is applied so the flange is stocky and able to carry a stress very close to full yield stress to avoid local buckling of the free edge of flange/face plate. This is visualized as Area A in Figure 10.

The buckling capacity of plates and stiffeners is unified in a single toolbox applicable both for the prescriptive buckling check and the FE buckling assessment. This toolbox, referred to as the Closed Form Method (CFM), is a further development of the ultimate strength/buckling capacity method in CSR-BC and the prescriptive method in CSR-OT. The ultimate capacity of plate and stiffeners are defined as the ultimate limit state when the membrane Von Mises stress reaches specified minimum yield stress either in the plate or at the top of the stiffener. The main updates of the Closed Form Method are:

- Elastic buckling limit for stiffeners is included, as in the FE buckling method of CSR-OT.
- Torsional buckling of stiffeners has been replaced with a warping stress component in the lateral buckling formulations for stiffeners.
- For short wave plate buckling pattern (longitudinal plate buckling), the rotational support along the long plate edge from the stiffener is taken into account.

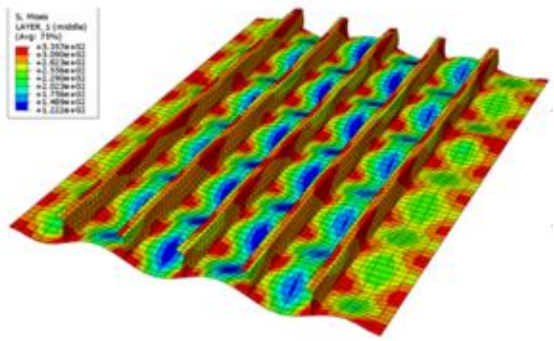
Figure 10 Critical buckling stress versus slenderness



4.5.1 Prescriptive Buckling Requirements

Buckling of plates and stiffeners subjected to hull girder stresses are extended from the uni-axial buckling assessment in CSR-OT, where hull girder bending and hull girder shear are checked separately. In the harmonised Rules the prescriptive buckling assessment is based on a combination of hull girder bending, hull girder shear and local pressure similar to CSR-BC. Prescriptive buckling assessment shall be carried out both for acceptance criteria AC-S (frequent loads, static loads) and AC-SD (extreme loads in seagoing conditions, static + dynamic loads). This is also an increase in scope compared with CSR-OT which has only prescriptive buckling requirement for acceptance criteria AC-SD.

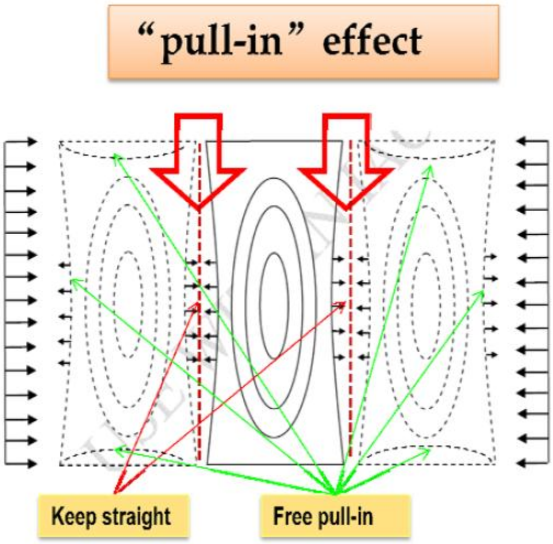
Figure 11 Von Mises membrane stresses in a non-linear FE model of a stiffened panel at ultimate capacity. Maximum stress is equal to the specified minimum yield stress.



4.5.2 FE buckling

For FE buckling the scope is the same as in CSR-OT, however the method has been changed from the semi-analytical advanced buckling assessment method (PULS) to the Closed Form Method (CFM). The elastic buckling limit for the webs of primary supporting structures in CSR-OT has been replaced with the ultimate capacity based on plate panel without pull-in constraint at the plate edges, to avoid some of the conservatism in the elastic buckling criteria in CSR-OT, see Figure 12. The buckling control of pillars and cross ties is the same as in CSR-OT.

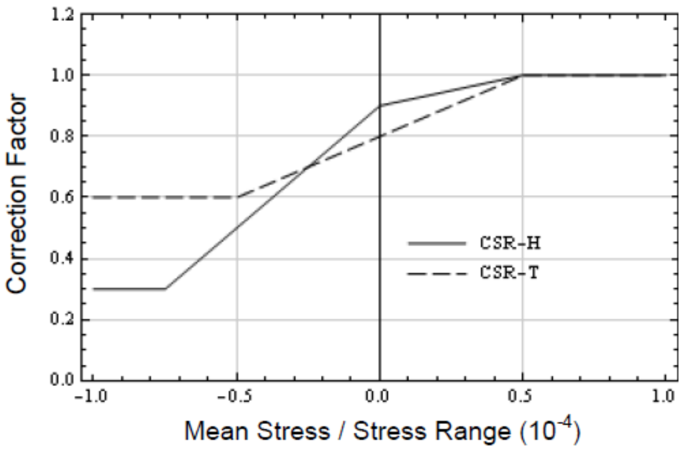
Figure 12 “Pull-in” effect versus plate edges without in-plane constraint



4.6 Fatigue

As in CSR-OT, the target fatigue life of 25 years based on North Atlantic Environment is applied. The fatigue assessment in both the simplified assessment for longitudinal stiffeners and the FE based assessment is based on a common hot spot stress approach. This is similar to the FE based method applied in CSR-OT, while for simplified fatigue assessment or longitudinal stiffeners CSR-OT applies a nominal stress approach. As explained in 4.1.2, the reference loads applied in fatigue assessment are based on the Equivalent Design Wave (EDW) concept with a probability level of 10^{-2}. The fatigue life is based on the EDW load set giving the maximum stress range after all corrections are made, e.g. mean stress correction and correction due to thickness effect. The mean stress effect concept from CSR-OT has been maintained. However the parameters are modified resulting in a reduced effective stress range in cases of high compression, and a higher effective stress range in cases of mean stress close to zero, see Figure 13.

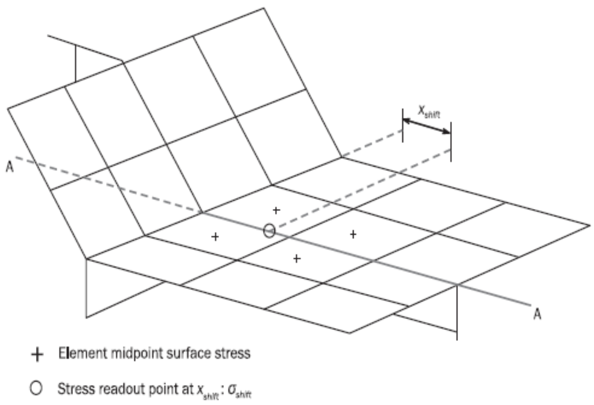
Figure 13 Mean stress correction factor applied for welded joints at longitudinal stiffeners harmonised CSR and CSR for oil tankers



4.6.1 Increased scope for FE fatigue

Basically the scope for fatigue assessment based on very fine mesh FE where the mesh size is about the same as the plate thickness (txt mesh) has been kept the same as in CSR-OT. i.e. lower hopper knuckle as shown in Figure 14. However fatigue screening for some of the details which are mandatory for yield check with fine mesh FE models (50 x 50 mm mesh) has been added, e.g. upper hopper knuckle and stringer heel. For screening of the hot spot stresses, membrane stresses from the fine mesh model (50 x 50 mm mesh) multiplied with tabulated stress concentration factors are used.

Figure 14 Very fine mesh model - Stress read out points for web stiffened cruciform connection



4.6.2 Detail design standard

As in CSR-OT, the harmonised rules contain a number of details where a detail design standard is given. The purpose of this standard is to apply well proven criteria with respect to fatigue performance and to reduce the scope for FE fatigue assessment. The number of details covered by the detail design standard is increased compared with CSR-OT.

4.7 Welding

In general the welding criteria are based on CSR-OT, e.g. the fillet weld requirements. This is also the case for various fillet weld locations, where the required size of fillet welds are dependent on the 'as-built' thickness of the abutting plate of the connection with a minimum size for lower plate thicknesses. A study has been carried out to verify the relative strength of fillet weld connections based on net-scantlings compared to the 'as-built' condition. For high stress areas, the requirements for full penetration welds, partial penetration welds, as well as fillet welds when applicable, are better defined in the harmonised Rules.

4.8 Ships in operation

4.8.1 Survey moved to UR Z.

An important change brought into the harmonised CSR was made through the reorganisation of the Rules and the IACS Unified Requirements (UR) for Hull Surveys (Z10 series). IACS decided to group all the requirements regarding surveys into the applicable UR Z10s for clarity and for avoiding an unnecessary repetition and simply remove them from the CSR-H.

4.8.2 Renewal criteria related to global corrosion

The renewal criteria for global corrosion were slightly modified with regard to the hull girder strength, especially for the section moduli at deck and at bottom. IMO requires that the section modulus at deck and at bottom using the measured thicknesses cannot be less than 90% of the ones calculated with the gross offered thicknesses.

If the actual reduction of the cross sectional area of the gross offered thickness of items in the deck and bottom zones, of a given transverse section, which contribute to the hull girder strength is less than 10% for the deck and bottom zones, the hull girder strength criteria of this transverse section is satisfied and the section modulus calculations of the deck and bottom zone areas with measured thicknesses need not be carried out.

5 Main GBS issues not directly covered by CSR-H

There are a number of GBS functional requirements listed in Section 2 above that are only partially included or not included in the structural Rules of the CSR-H. These functional requirements are covered in other documents produced by IACS and are typically referenced or introduced into the individual Class Society Rules. These are briefly summarized in the following sections.

5.1 Survey

The GBS function requirements addressing new construction and future in-service survey are covered in IACS documents IACS UR Z23 “Hull survey for new construction” and the UR Z10 series, respectively. As previously mentioned in Section 4.8.1 above, detailed survey-related requirements are not included in the structural requirements of the CSR-H. However the CSR-H does introduce and reference some of the survey concepts as follows:

- General concept of surveys during construction and while in-service.
- Construction and fabrication fit-up, welding and non-destructive testing.
- Areas subject to special attention.
- Tank strength and leak testing.

5.2 Human elements

The GBS function requirements addressing the human element will be covered in a newly developed IACS Guideline on human element aspects. This Guideline will include some of the industry best practices that IACS members have encountered. The CSR-H does introduce and reference some human element concepts or considerations as follows:

- International Labour Organization (ILO) implemented by National Administrations or the Society on their behalf.
- Lighting and ventilation arrangement considerations from the relevant requirements of International Conventions such as SOLAS and MLC2006 Regulation 3.1.
- Noise consideration from the relevant requirements of SOLAS Ch II-1, Reg.3-12 and the mandatory document “The Code on Noise Levels On-board Ships” adopted at MSC.337(91).
- Vibration consideration from the relevant statutory requirements such as MLC 2006 Regulation 3.1.
- Ship structure access.

5.3 Ship Construction File

The compilation of a Ship Construction File is associated with the GBS functional requirement on design transparency. IMO circular MSC.1/Circ.1343 *Guidelines for the Information to be Included in a Ship Construction File* (SCF), documents for each GBS functional requirement the basic design and operational information of the ship to be included in the SCF. This initial design information, which is also to be updated as appropriate throughout the ship's life, is intended to be kept on board the ship and/or ashore to facilitate safe operation, maintenance, survey, repair and emergency measures. IACS document IACS UR Z23 “Hull survey for new construction” covers the creation of the SCF and the UR Z10 series cover the maintenance and updating of the SCF. Detailed information on the ship construction file is not included in the structural requirements of the CSR-H.

In general the GBS are not directly applied to individual ship designs or contain regulations that Shipyards or Owners are directly responsible for. However, in this case Shipyards or Owners, depending on whether in the construction or in-service phase, are responsible for the development and maintenance of the SCF and Class Societies will be checking the SCF as indicated in the UR Z23 and UR Z10 series.

5.4 Recycling

The GBS functional requirement addressing recycling requires lists of materials used in the construction of the ship and later during any in-service modifications be maintained for future ship recycling purposes. The compilation and maintenance of the list of materials is one of the items included in the Ship Construction File mentioned above. As such the documentation covering these lists during construction and in-service are covered in IACS documents IACS UR Z23 "Hull survey for new construction" and the UR Z10 series, respectively. Detailed recycling-related requirements are not included in the structural requirements of the CSR-H.

Similar to the comment made with regard to the SCF, the list of materials to be assembled and maintained for future recycling is a regulation that Shipyards or Owners are directly responsible for. However, in this case Shipyards or Owners, depending on whether in the construction or in-service phase, are responsible for the development and maintenance of the materials list and Class Societies will be checking for the existence of the SCF as indicated in the UR Z23 and UR Z10 series.

6 Consequence Assessment

A consequence assessment (CA) was carried out by IACS in order to determine the effect of applying the Harmonised Common Structural Rules (CSR-H)[1]. The CA results presented are based on availability at the time of writing of this paper, as the CSR-H are developed and changed over time, future CA reports presented based on those future rule versions may vary.

In the CA evaluation IACS Societies used representative designs from major builders in Asia – the oil tankers used in the CA are listed in Table 1. The designs assessed in the CA are compliant with the July 2010 version of the CSR-OT. It is noted than an equal number of bulk carriers were also used in the CA. For the consequence assessment the design were not altered in any way. Strake size, seam locations, material properties, stiffener spacing, etc., have not been altered.

Table 1 Principal particulars of the oil tankers

ID	Category	LBP (m)	Bmld (m)	Tsc (m)	Dmld (m)	Dwt. (tonnes)
OT1	VLCC	319	60.0	22.6	30.4	318000
OT2		324	60.0	21.0	29.0	330000
OT3	Suezmax	264	48.0	17.0	23.7	158000
OT4		264	50.0	17.0	23.2	163000
OT5	Aframax	240	42.0	15.0	21.5	97000
OT6		240	44.0	14.8	21.0	103000
OT7		234	42.0	15.0	21.2	105000
OT8	Panamax	220	32.3	14.7	21.2	76000
OT9		219	32.2	14.5	20.9	74000
OT10	Handymax	176	32.2	12.6	18.2	50500

Each classification society carried out the assessment of one oil tanker using their respective software.

[1] Harmonised CSR, External Release 1 April 2013

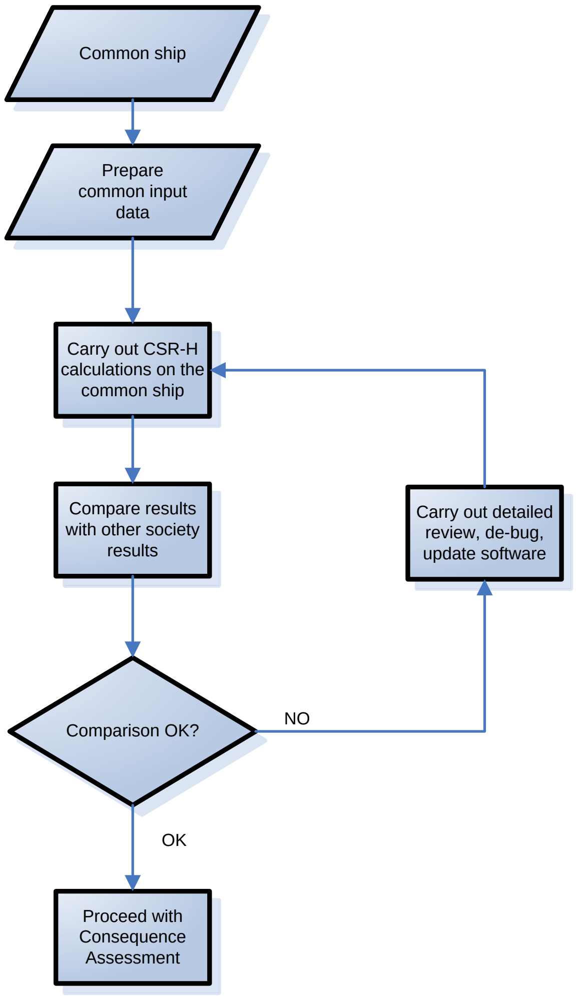
Before the CA is carried out it is important to verify that the Rules have been correctly interpreted and implemented in the Society's software. To provide correct implementation "cross checking" is carried out using common ships; one common tanker and one common bulk carrier were used in the cross checking activity. An integral part of the consequence assessment is the cross checking activity whereby the results of the software is cross checked against all other classification society software.

The ships used in the cross checking were not used in the consequence assessment.

The CSR-H rules are applied to the common ship, and the output is compared. The classification society can proceed to CA only when a satisfactory cross checking comparison is completed. Cross checking was carried out for prescriptive as well as finite element requirements.

The cross checking process is illustrated in Figure 15.

Figure 15 Process for cross checking



The following Rule evaluation criteria were cross checked:

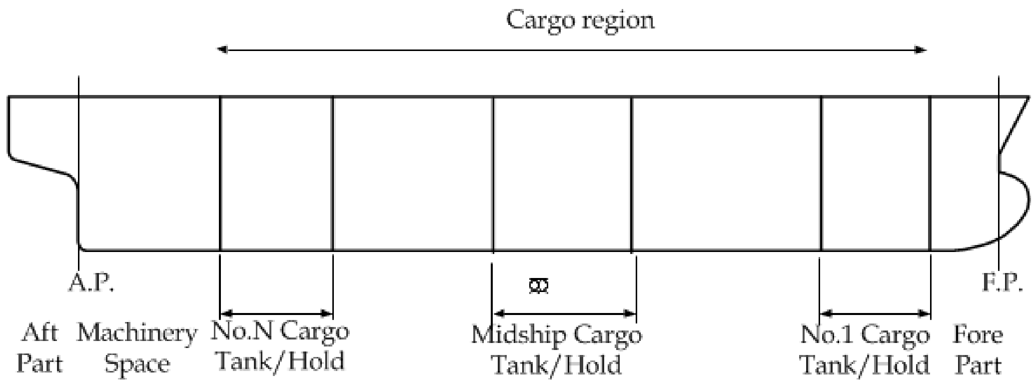
- Hull girder longitudinal strength,
- Hull girder ultimate strength,
- Minimum thickness & slenderness requirements,

- Local strength,
- Prescriptive buckling,
- Simplified fatigue assessment,
- Direct strength analysis – buckling assessment,
- Direct strength analysis – yield assessment.

6.1 Scope of CA

Representative cross sections were selected along the ship length from the aft part to the fore part, and CA results provided at these regions. See Figure 16 for overview of the locations.

Figure 16 Overview of consequence assessment locations



For each of the regions listed below a section at about mid-length was selected for reporting results:

- Aft Part.
- Machinery Space.
- No. N cargo tank, (i.e. the aft-most cargo tank).
- Midship cargo tank; one cross section is reported in the midship cargo oil tank.
- No.1 cargo tank, (i.e. the fore-most cargo tank).
- Fore Part.

In addition to the above locations one selected transverse bulkhead and primary support member results were also assessed:

- Transverse bulkhead; the forward bulkhead in the midship cargo tank.
- Horizontal stringers on the selected transverse bulkhead.
- Primary support members – transverse web frame in the midship cargo tank.

Prescriptive results for all strakes and stiffeners were evaluated for both CSR and CSR-H covering the regions listed above.

6.2 Scantling impact

The effect of applying the harmonised CSR Rules was compared against the offered scantlings. Prescriptive buckling capacity evaluation and direct strength assessment (for yielding and buckling assessment) is based on the offered design. Whenever the offered design does not meet the Rule requirements simple estimates were made in order to evaluate the design impact. The estimates calculated are approximations of the scantlings that may be needed to satisfy the CSR-H requirements. In the computation of the estimates approximate methods have been used to arrive at the scantling estimates, and the designs have not been modified. Similarly, where the offered scantlings are higher than that required, the designs have not been changed to reflect possible reductions. Therefore the final effect on design scantlings will not become apparent before new designs have been generated which take into account both increases and decreases.

The detailed consequence assessment results are reported in separate individual Technical Background reports. These detailed reports are available on the IACS website (www.iacs.org.uk). In the reports, results are provided for each strake and stiffener covering the prescriptive Rule requirements where the locations that have requirements above and below the offered scantlings may be noted. Direct strength assessment results for each section listed in Section 6.1 above are also included.

In the following sections a summary of the general trends is provided for the oil tankers only.

6.2.1 Midship cargo tanks

VLCC - midship cargo oil tank

- Scantling increase is seen on the:
    - inner bottom plating (+0.5mm) due to local pressure requirements; and
    - longitudinal bulkhead upper strakes in way of the main deck plating (+0.5 & +2.5mm) due to hull girder buckling requirements.
- Longitudinal stiffeners on deck stringer plate, sheer strake, upper part of inner hull and longitudinal bulkhead are not sufficient to meet CSR-H hull girder buckling requirements: CSR-H buckling utilisation factor of 1.0 to 1.4.
- Longitudinal stiffeners on side shell in way of water line are partly failing in simplified fatigue requirements.

Suezmax - midship cargo oil tank

- Scantling increase seen on; inner bottom, inner hull, and horizontal side stringer: +0.5mm and bottom shell: +2.0mm. The governing criterion is local pressure requirements.
- Some increase is necessary on; longitudinals due to local pressure requirements, and longitudinals on main deck, upper part of long bulkhead and upper part of inner hull are failing in prescriptive buckling.
- Some bottom shell longitudinals have a fatigue life of only 21 years.

Panamax - midship cargo oil tank

- Scantling increase is seen on; the inner bottom, and inner longitudinal bulkhead (+0.5 mm). The governing criterion is local pressure.
- Longitudinals on centre and inner longitudinal bulkheads, sheer strake and main deck are not sufficient to meet local pressure requirements. An increase in the section modulus in the order of 16~59% will be necessary.
- Longitudinals on bottom and side shell plates are failing in CSR-H fatigue. The calculated fatigue is in the range 14 to 23 years.

Aframax - midship cargo oil tank

- Scantling increase is seen on the:
    - Inner bottom plating and inner hull plating, (+0.5mm to 1.0mm). Governing criterion is local pressure.
    - Longitudinal bulkhead plating (+1.5mm). Governing criterion is FE buckling.
    - Keel plating: +2.5 mm, sheer strake plating: +2.0mm. Governing criterion is minimum thickness.
- Longitudinal stiffeners on the inner hull, longitudinal bulkhead and outer shell were not sufficient to meet CSR-H local pressure requirements.

- Main deck longitudinals and upper part of long bulkheads were failing in buckling. Increase in section modulus will be necessary to meet buckling evaluation (increase in modulus up to +82%).
- Some bottom shell longitudinals have a fatigue life from 22 to 24 years.

6.2.2 Foremost cargo tank

VLCC - foremost cargo oil tank

- Limited increase is observed due the prescriptive assessment. Part of bilge plating: +0.5mm due to local pressure requirements.
- A few longitudinals on the side shell in way of the water line have a fatigue life of 24 years.

Suezmax - foremost cargo oil tank

- Some increase is seen for the main deck plating for one of the Suezmaxes (increase range of +3.5mm to +6.5mm). Governing criteria is local pressure.

Panamax - foremost cargo oil tank

- Some strakes on the inner bottom, hopper, centre & inner longitudinal bulkheads see an increase due to local pressure: 0.5 ~ 1.0mm.
- Generally limited increases to the longitudinal stiffeners.

Aframax - foremost cargo oil tank

- Centre line girder and few strakes on the inner hull: +0.5mm. Governing criterion is local pressure.

6.2.3 Aftmost cargo tanks

VLCC - aftmost cargo oil tank

- No increase is observed due the prescriptive assessment.
- A few longitudinals on the side shell in way of the water line have a fatigue life of 23 years.

Suezmax - aftmost cargo oil tank

- Some increase is observed either due to local pressure or increased minimum thickness.
    - Sheer strake: +1.0mm
    - Some strakes of the inner hull: +0.5mm
    - Side shell: +0.5mm

Panamax - aftmost cargo oil tank

- A few strakes on the inner bottom, centre longitudinal bulkheads see an increase due to local pressure: 0.5 ~ 1.0mm.
- Generally limited increases to the longitudinals' stiffeners.
- Longitudinals on side shell plate have a fatigue life of 8 to 18 yrs.

Aframax - aftmost cargo oil tank

- Inner bottom: +0.5mm, inner hull: +1.0mm, bilge plating: +0.5mm and sheer strake: +2.0mm. Governing criterion is local pressure.
- Longitudinals on inner hull, and upper deck adjacent to sheer strake not sufficient to meet local pressure requirements.
- A few longitudinals on the longitudinal bulkhead and side shell have a fatigue life of 20 and 21 years.

6.2.4 Fore end

VLCC - fore end

- Part of bilge plating needs to be increased +0.5mm to +1.5mm. Governing criteria is local pressure.
- Deck longitudinals needs to be increased to meet the local pressure requirements (increase in modulus up to 30%).

Suezmax - fore end

- No significant increase is observed.

Panamax - fore end

- No significant increase is observed.

Aframax - fore end

- Plating and longitudinals on the deck are not sufficient to meet local pressure requirements.
    - Upper deck plating: +0.5mm ~ +1.0mm.
    - Longitudinals on upper deck: +24%.

6.2.5 Aft end

VLCC - aft end

- No scantling increase is observed.

Suezmax - aft end

- No significant increase is observed.

Panamax - aft end

- On one of the Panamax tankers an increase on side shell plating is necessary due to minimum thickness increase (up to +1.0mm).

Aframax - aft end

- No significant increase is observed.

6.2.6 Machinery Space

VLCC - machinery space

- No significant scantling increase is seen.

Suezmax - machinery space

- Increase is seen on sections of bottom shell and side shell due to increased minimum thickness: range of increase +2.0mm to +5.5mm.

Panamax - machinery space

- Side shell plating increase due to increased minimum thickness; up to +1.5mm.
- No significant scantlings increase for the longitudinal stiffeners.

Aframax - machinery space

- Side shell plating increase due to increased minimum thickness; up to +1.5mm.
- No scantlings increase for the longitudinal stiffeners.

6.2.7 Direct Strength Assessment

Direct strength assessment was carried out in accordance with the Rules covering both yielding and buckling assessment. Locations covered were:

- Midship cargo oil tank; and
- Foremost cargo oil tank; and
- Aftmost cargo oil tank.

In the following a summary is provided for each category.

VLCC CSR-H FE assessment has been carried out for the midship, foremost cargo oil tank, and aft most cargo oil tank.

Yielding assessment:
- Extremely-limited part has impact on scantlings due to direct strength assessment.

Buckling assessment:
Buckling assessment leads to scantling impact. Notably, the following structure has areas which do not satisfy CSR-H buckling requirements:
- Midship cargo oil tank: longitudinal bulkhead upper part, bottom girders, horizontal stringers, deck in way of inner hull plate and floor plating in way of bottom brackets.
- Foremost cargo oil tank: Side shell fore part, longitudinal bulkhead upper part, bottom girders, horizontal girders, collision bulkhead, deck fore part.
- Aftmost cargo oil tank: bottom plating, bottom girders, horizontal girders, bilge hopper transverse web.

Suezmax CSR-H FE assessment has been carried out for the midship, foremost cargo oil tank, and aft most cargo oil tank.
Yielding assessment:
- No significant impact on scantlings.

Buckling assessment:
- There are increased requirement to plate thickness and to stiffener section modulus as detected by FEA buckling check.

Fine mesh assessment in the midship cargo oil tank:
- No significant impact on scantlings.

Panamax CSR-H FE assessment has been carried out for the midship, foremost cargo oil tank, and aft most cargo oil tank.
CSR-H FE assessment midship cargo oil tank
- Generally, the current CSR design complies with CSR-H FE yielding and buckling requirements: Maximum scantling consequences, 2.0 mm.

Panamax CSR-H FE foremost cargo oil tank
- No significant impact on scantlings from yielding assessment.
- The scantling consequences are found mostly from buckling requirements.

Panamax CSR-H FE aftmost cargo oil tank
- No significant impact on scantlings from yielding assessment.
- The scantling consequences are found mostly from buckling requirements.

Panamax Fine Mesh Analyses (Midship)
- Fine mesh analyses within the midship region were carried out with 20 locations including lower hopper knuckle.
- Generally, the current CSR designs comply with CSR-H yielding requirements of fine mesh analyses. Scantling consequences in way of openings on the double side web of a typical web and openings on the vertical web of a typical web are notable.

Aframax CSR-H FE assessment has been carried out for the midship, and foremost cargo oil tank.
Yielding assessment
- Scantling impact on longitudinal bulkhead in way of the transverse bulkhead.
- Possible local scantling increase after fine mesh.

Buckling assessment
- Scantling impact is observed for the midship section: Inner hull, longitudinal bulkhead, stringer in way of transverse bulkhead, transverse bulkhead, and typical web frames.

At the time where this paper is written, the application of the CSR-H April version leads to an overestimation of results for the buckling failure mode at the ends of the cargo area. This is not in line with the in-service feedback of the IACS members. Consequently, IACS has launched a reassessment study of the CSR-H especially for the loads of the foremost and aftmost cargo tanks. Non-linear coefficients are under re-examination for possible input into the CSR-H loads used for the strength assessment.

7 Schedule

The harmonised CSR has followed an aggressive development and review schedule balancing the need to receive industry feedback with the deadline of the submission to the IMO for the GBS verification audits. The schedule has also allowed for feedback from the consequence assessment studies to be used to calibrate and refine the rules. This has been performed using an iterative cycle as shown in Table 2.

Table 2 Long-term harmonised CSR Schedule

Item	Schedule
First draft	1 Jul 2012
1st Industry Review	1 Jul – 31 Dec 2012 (6 months)
Feedback/Re-work	1 Jan – 31 Mar 2013 (3 months)
Second draft	1 Apr 2013
2nd Industry Review	1 Apr – 31 Aug 2013 (5 months)
Feedback/Re-work	1 Sep – 31 Oct 2013 (2 months)
Third (TC) draft	1 Nov 2013
TC Review	1 Nov – 15 Dec 2013 (1.5 months)
IACS Adoption	December 2013
Final clean-up	15 Dec – 1 Feb 2014
Release Rules	1 Feb 2014

8 Conclusion

The IMO Goal Based Standards (GBS), as far as they influence the structural requirements, are broadly covered within the IACS harmonised Common Structural Rules (CSR-H). The harmonised CSR address the GBS functional requirements within the rules themselves or are documented in the CSR Technical Background documents. Some of the GBS functional requirements are addressed outside of the CSR-H by other IACS documents such as Unified Requirements, Unified Procedures, Recommendations, etc.

In general the GBS is a set of “rules for rules” that Class Societies and Regulators will use during the development of rules and regulations and are not directly applied to individual ship designs. However there are related issues relevant to shipbuilders and owners such as documentation related to inventory of materials for future ship recycling and the Ship Construction File.

The harmonised CSR has been developed by blending the requirements and philosophies of the existing CSR-OT and CSR-BC and have benefitted from extensive review by industry. The IMO GBS has also influenced the development of the CSR-H. Feedback from the consequence assessment studies has also been used to fine tune the requirements. The CSR-H is on track towards final adoption in December of 2013 and the submittal to the IMO for the GBS verification audits.

9 Appendix

Fig. 1 Example of Basic Self-Assessment Sheet (extract)

Form: Basic Self-Assessment Sheet

<table>
<tr><td colspan="2">GBS Functional Requirements</td><td colspan="2">II.1 Design life</td></tr>
<tr><td>Documentation requirement No:</td><td colspan="3" rowspan="2">Statement of the design life in years used in developing the rules</td></tr>
<tr><td>1.2.1</td></tr>
<tr><td>Prepared by</td><td colspan="2">Date of Preparation</td><td>Date of Submission</td></tr>
<tr><td>HPT1,4,8,9</td><td colspan="2">28 February 2013</td><td></td></tr>
<tr><td colspan="2">Category in Self Assessment Report</td><td colspan="2">(a): No need to take action because already fully overed</td></tr>
<tr><td colspan="2">Rule Text</td><td colspan="2">TB</td></tr>
<tr><td colspan="2">Pt1 Ch1 Sec2 [3.3.1]
Pt1 Ch9 Sec1, 1
Pt1 Ch4 Sec1, 1.1.3</td><td colspan="2">Section 1.0 of TB Report Pt1 Ch3 Sec2 and Sec3
Ch1/Sec2/3.3.1, Ch9/Sec1/1, Ch3/Sec2/1.1, Ch3/Sec3/1.1, Ch4/Sec1,1.1.3
TB Report "The Definition of Extreme Loads"
TB Report "The Definition of Fatigue Loads"
TB Report "Corrosion Additions and Wastage Allowances"</td></tr>
<tr><td>Remarks</td><td colspan="3"></td></tr>
<tr><td colspan="4">Description/explanation for justification:

The design life of 25 years is specified in both of the rule and TB for extreme loads, fatigue loads, fatigue life and corrosion additions.

Pt1, Ch1, Sec2, 3.3.1 states that "A design life of 25 years is assumed ….".
TB Ref. for Pt1, Ch1, Sec2 [3.3.1] shows the definition of design life as quoted below.
[Quote]
The design life is the nominal period that the ship is assumed to be exposed to operating and/or environmental conditions and/or the corrosive environment and is used for selecting appropriate ship design parameters. The ship's actual service life may be longer or shorter depending on the actual operating conditions and maintenance of the ship throughout its life cycle.
The relationship between the design life that is specified for a ship at the time of design and construction and the actual safe working life is dependent on the operational history and the maintenance regime. It follows that two identical ships that are operated differently or maintained under different maintenance regimes may have different actual lives.
[Unquote]

Pt1, Ch9, Sec1, 1.1.1 General states that "…. The design fatigue life no to be taken less than 25 years.</td></tr>
</table>

*please add extra pages, as needed